Testing strong gravity with high throughput X-ray spectroscopy

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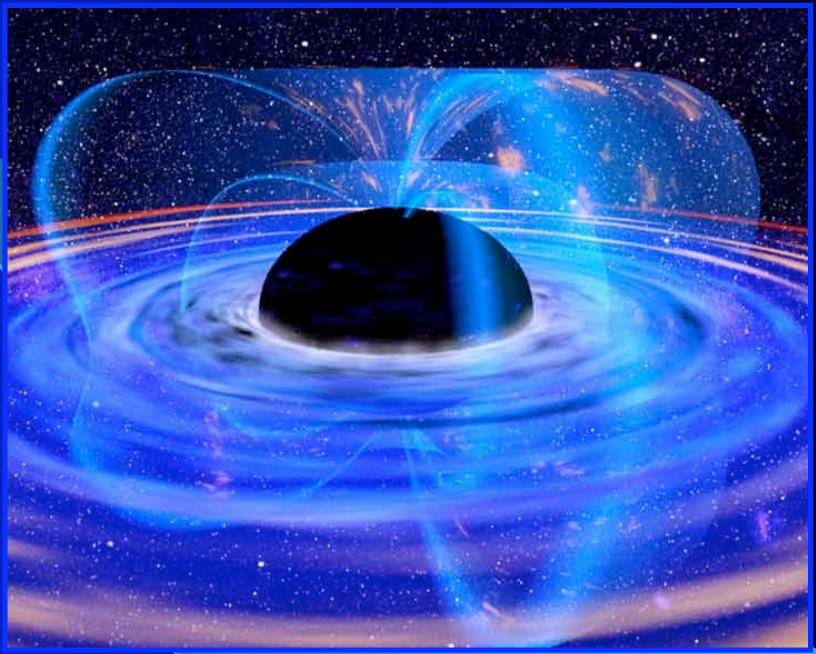
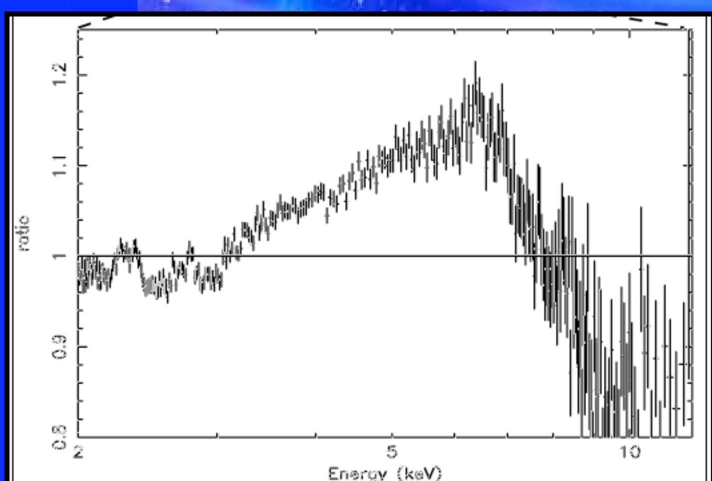
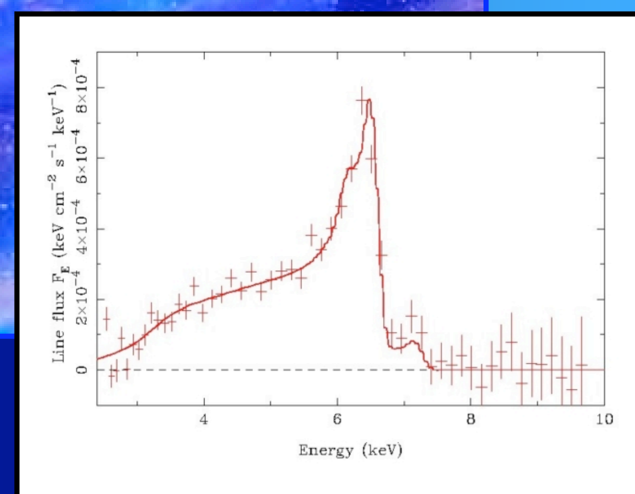
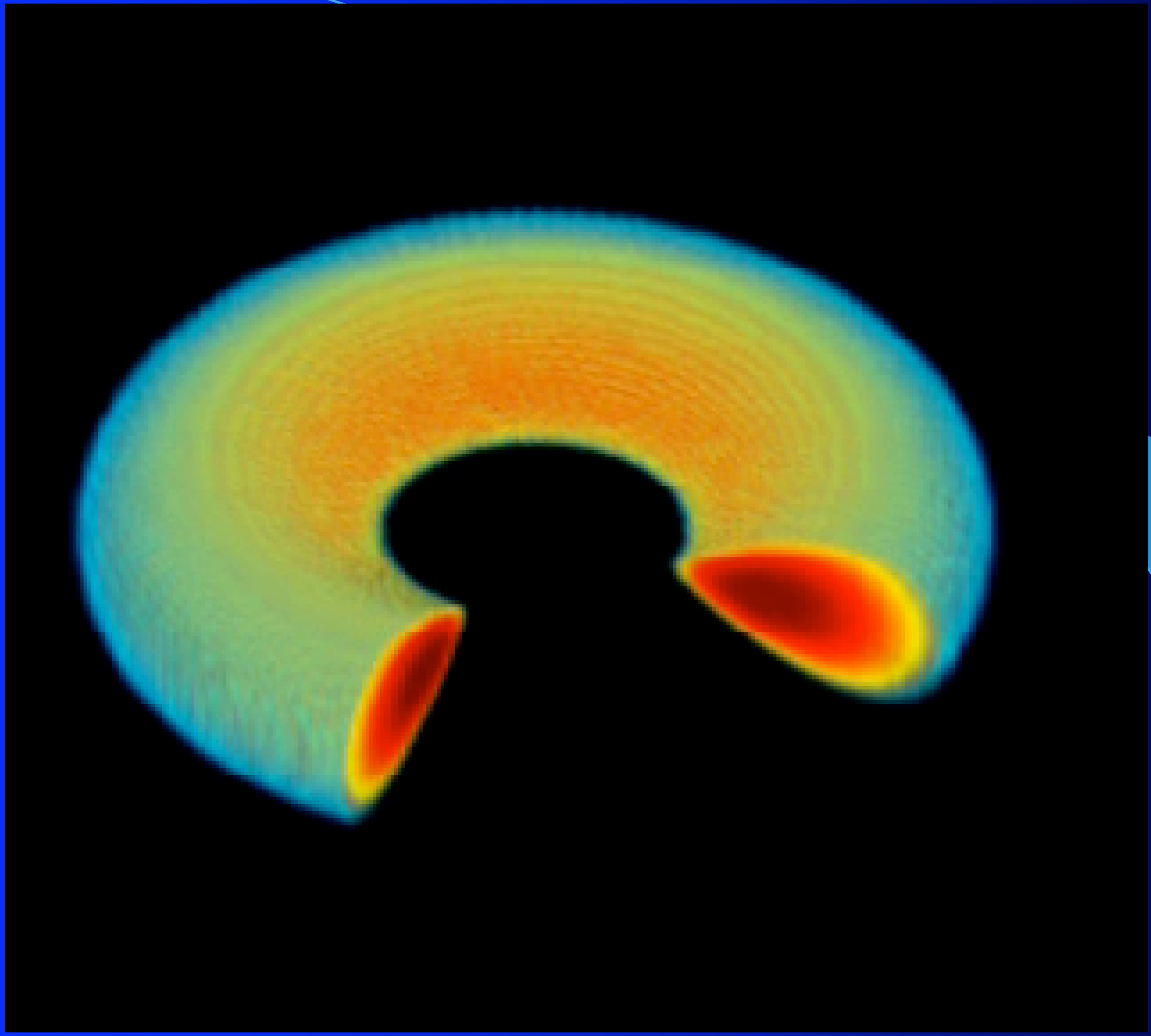


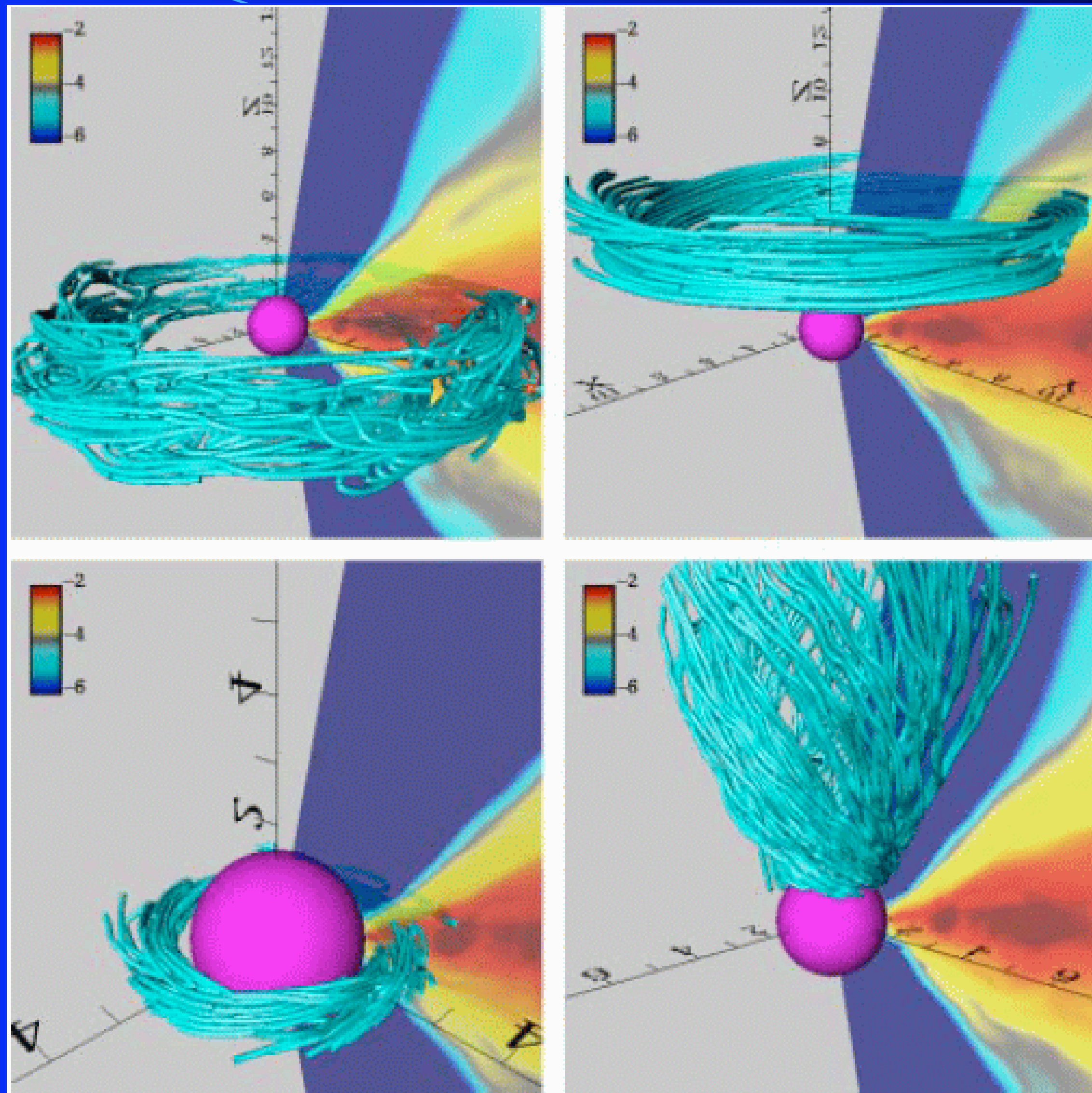
Constellation-X Black Hole Workshop
GSFC, 17-18th September 2004


ratio
0.8
0.9
1
1.1
1.2
2
5
10
Energy (keV)


Line flux F_E (keV cm^{-2} s^{-1} keV^{-1})
0
2×10^{-4}
4×10^{-4}
6×10^{-4}
8×10^{-4}
4
6
8
10
Energy (keV)



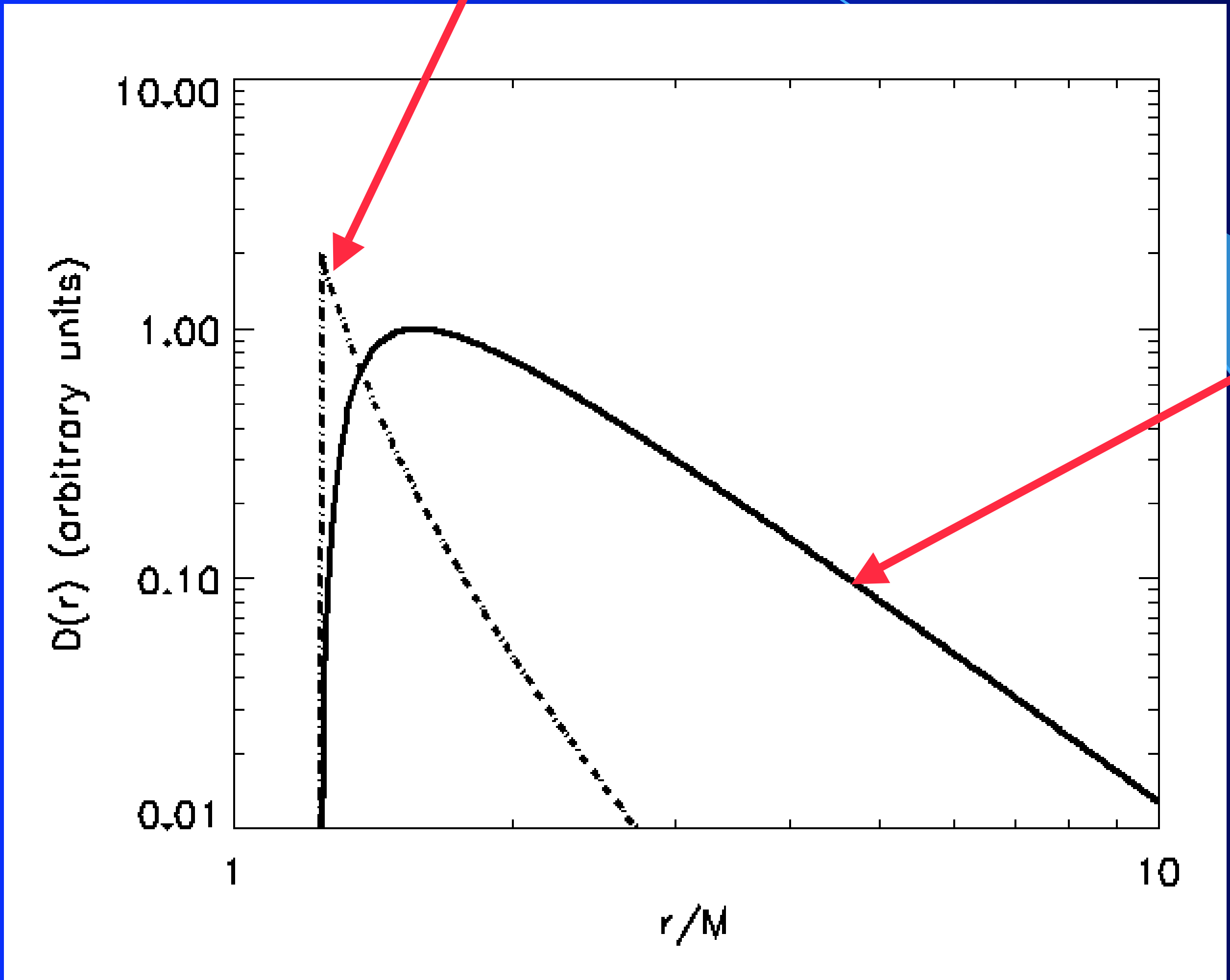
MHD accretion disk simulation
(Hawley & Krolik 2001)

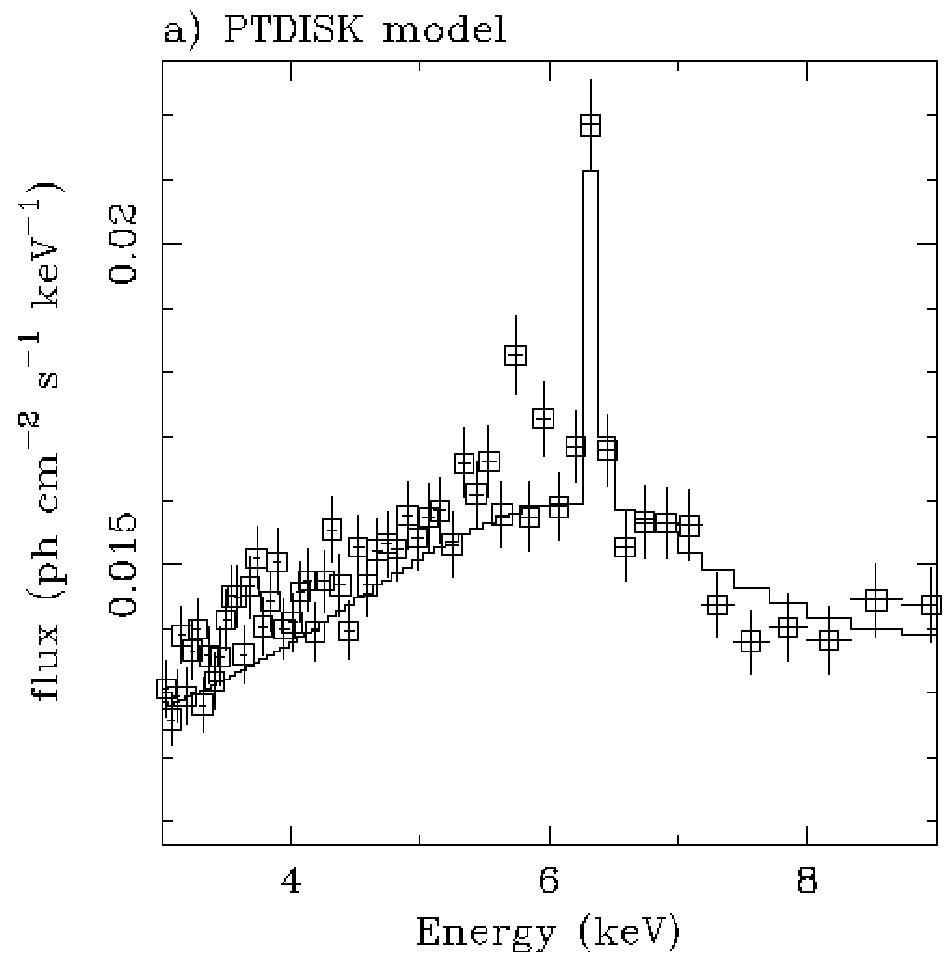


GR-MHD simulations by Hirose, Hawley & Krolik (2003)

Dissipation of work done by torque at radius of marginal stability

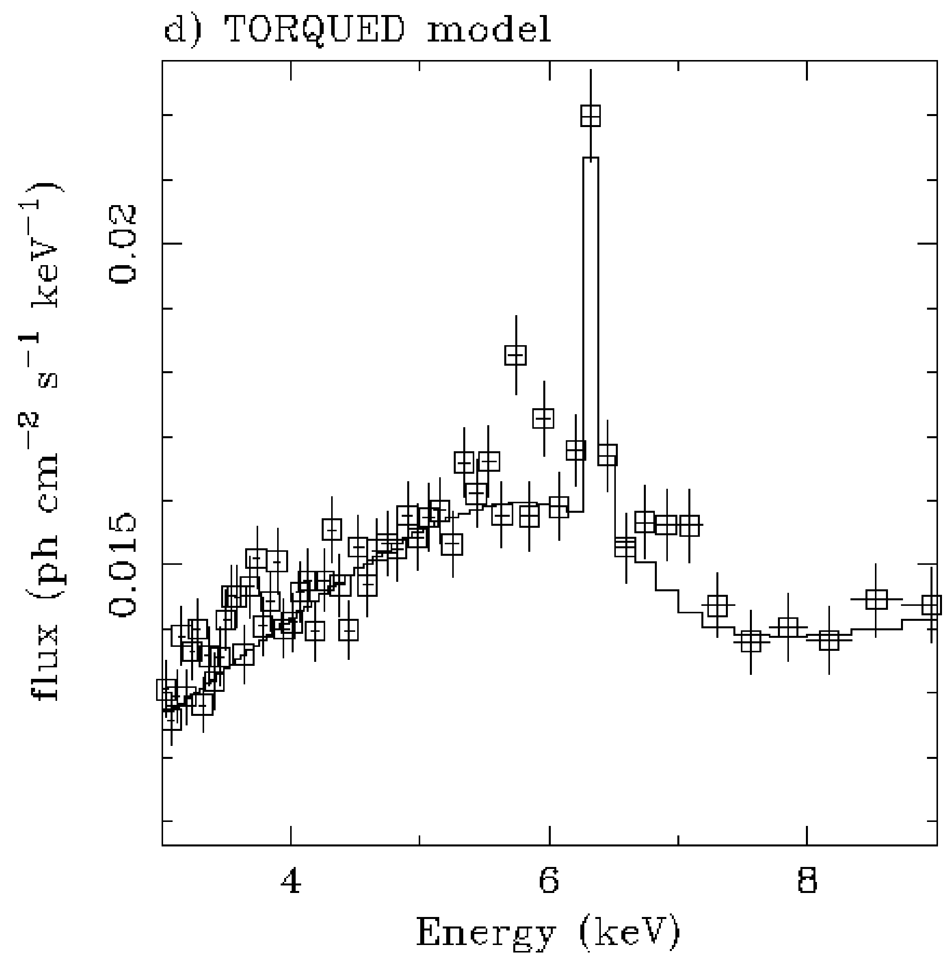
Accretion Luminosity





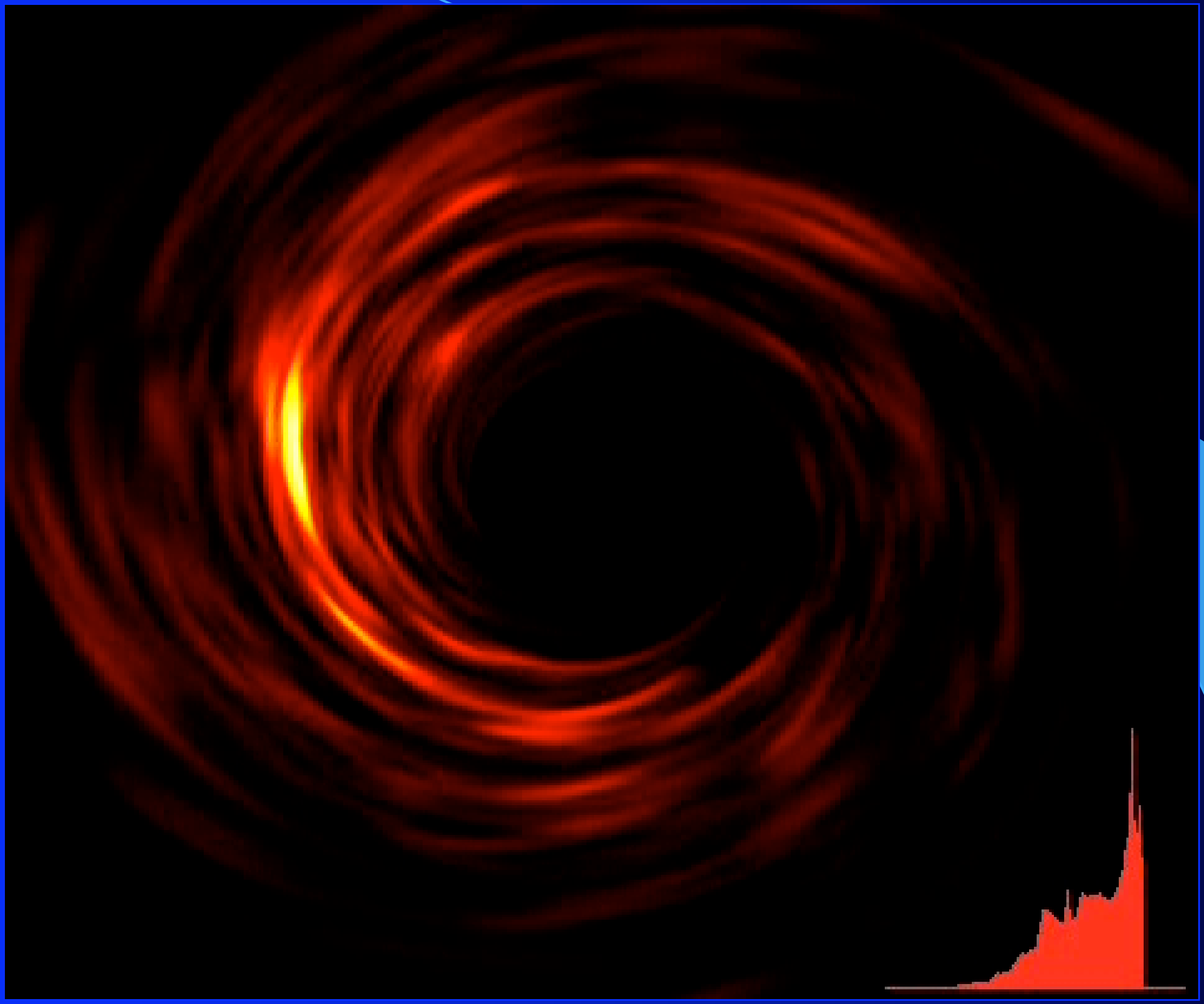
CSR et al (2004)

MCG-6-30-15
Fit with a Novikov-Thorne/Page-Thorne disk

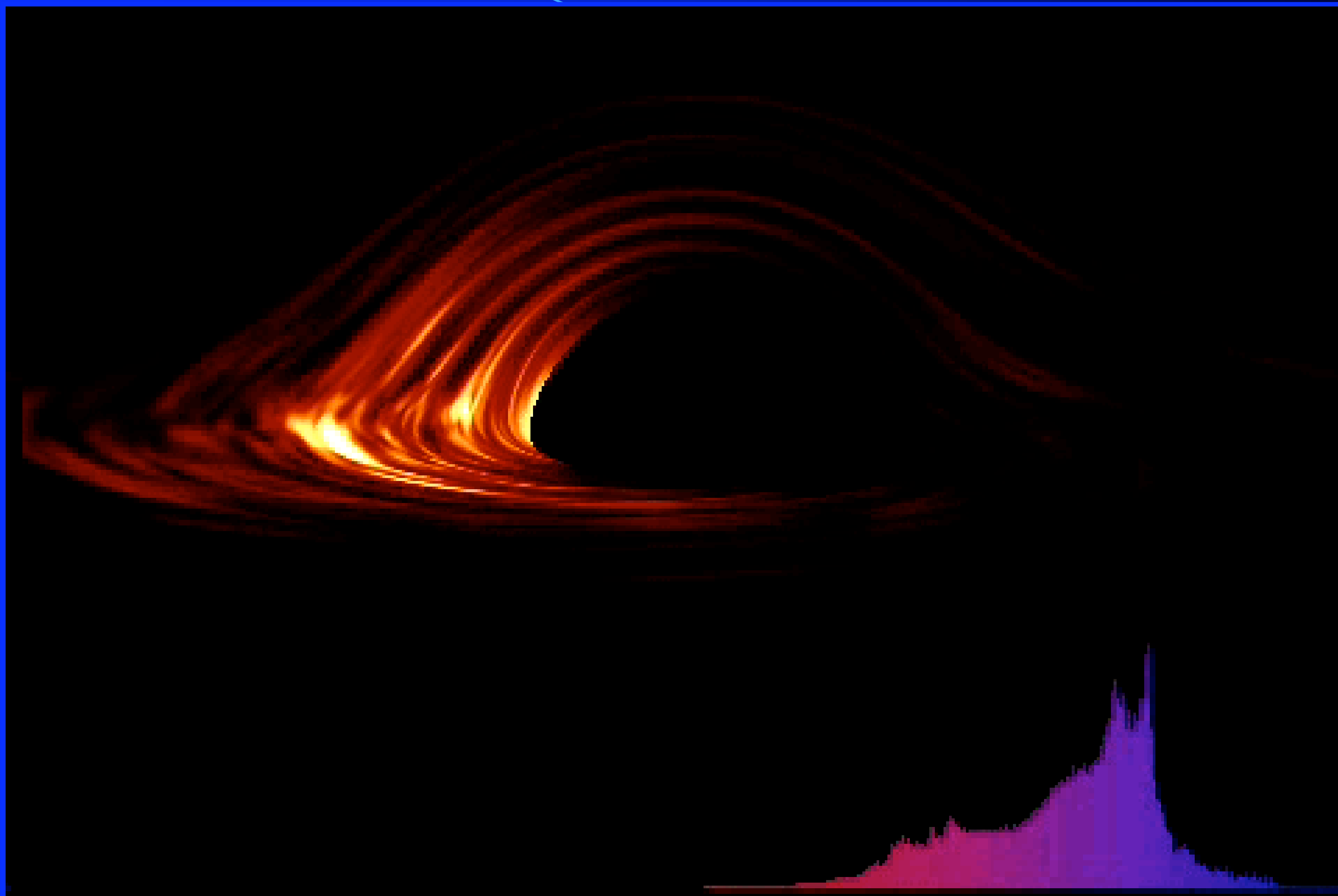


CSR et al (2004)

Fit with a Agol & Krolik torqued disk (need “infinite efficiency case)

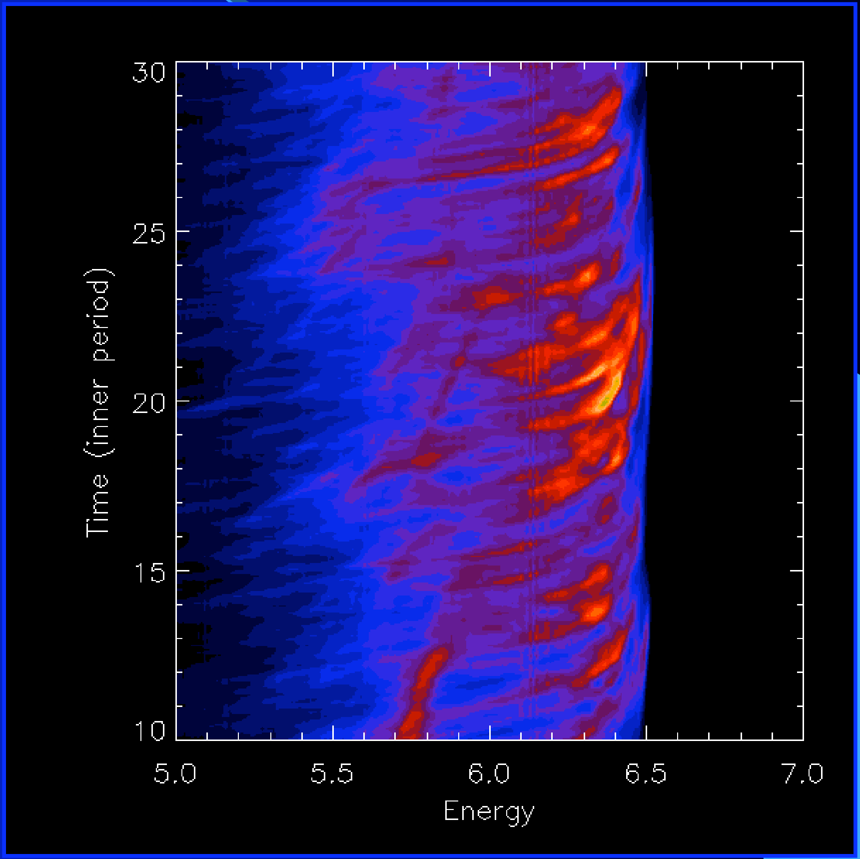


Armitage & CSR (2003)



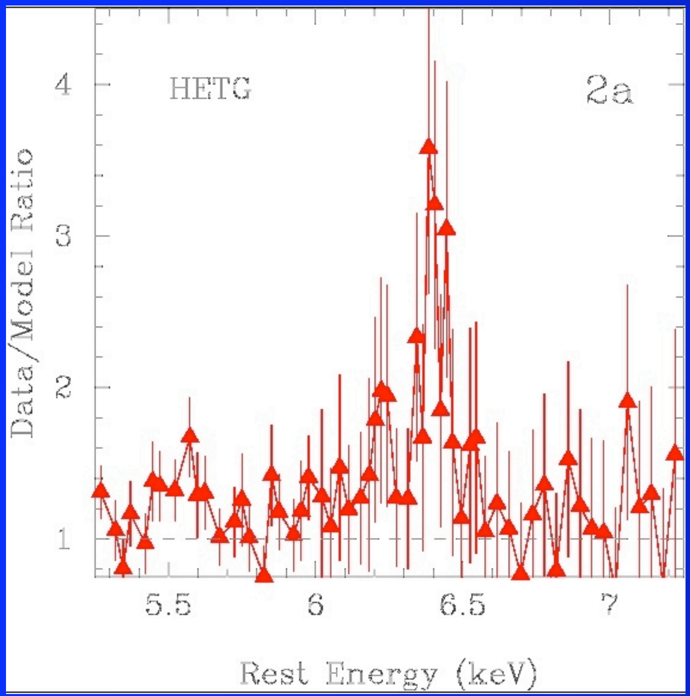
Iron line variability

- Con-X will allow detailed study of line variability
- See effects of non-axisymmetric structure orbiting in disk
  - Follow dynamics of individual “blobs” in disk
  - Quantitative test of orbital dynamics in strong gravity regime

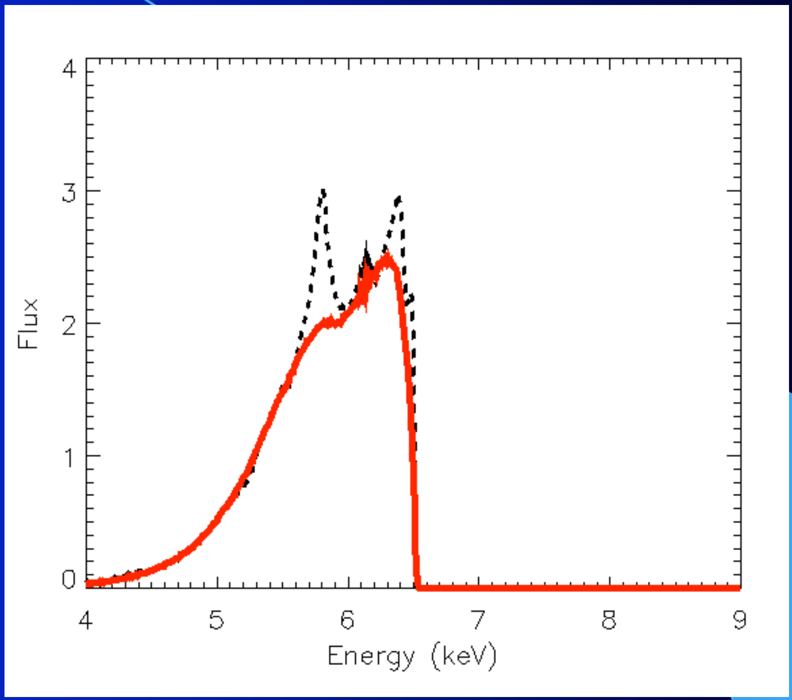


Armitage & CSR (2003)

Non-axisymmetric structure may have been seen already…



Chandra-HETG data on NGC3516 (Turner et al. 2002)

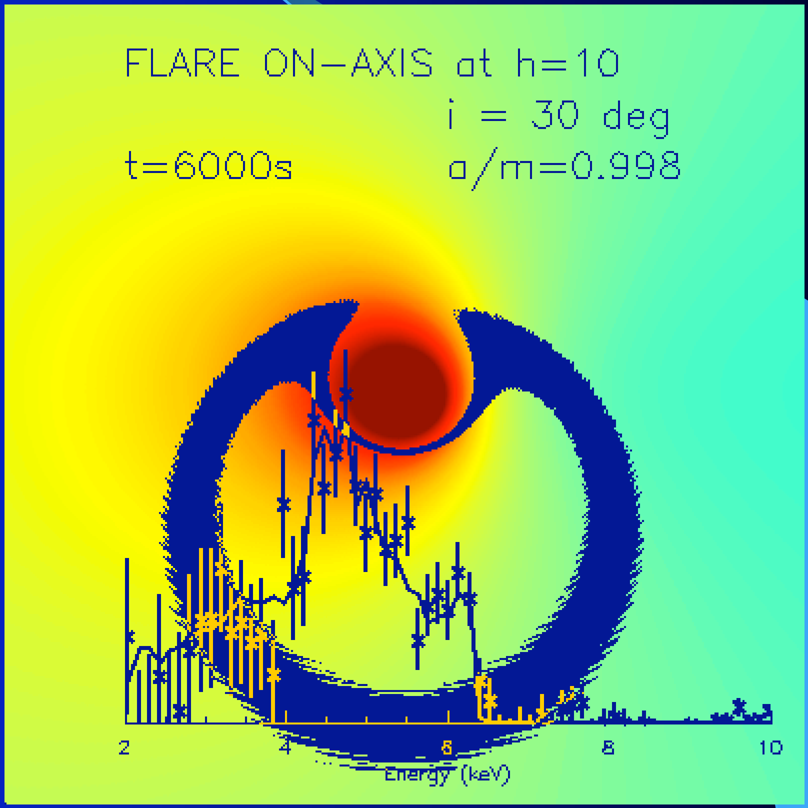


Simulation results for inclination of 20 degs (summed over 2 full orbits)

A prime science target for Astro-E2

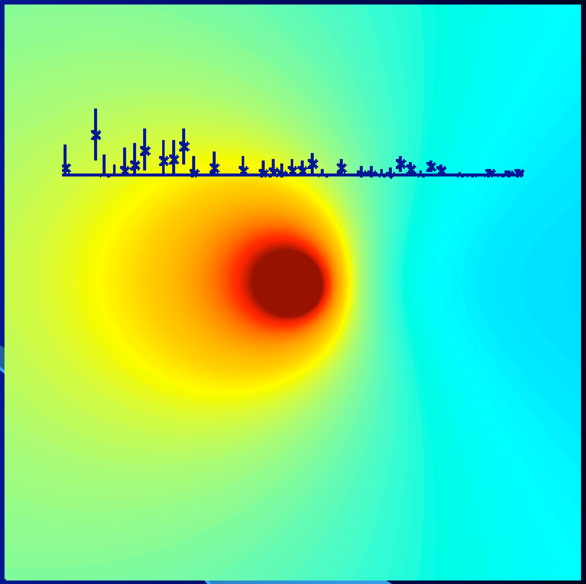
Relativistic iron line reverberation…

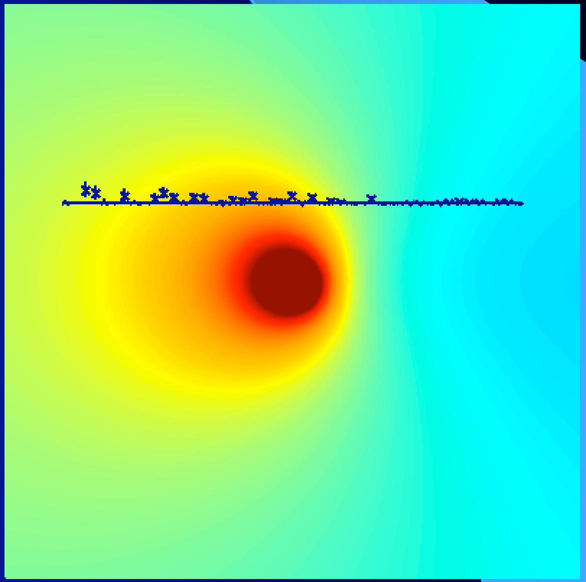
- Reverberation
  - X-ray source displays dramatic flares
  - Flare produces "X-ray echo" that sweeps across accretion disk
  - Iron line profile will change as echo sweeps across disk
  - Needs high throughput spectroscopy – but likely within reach of Con-X

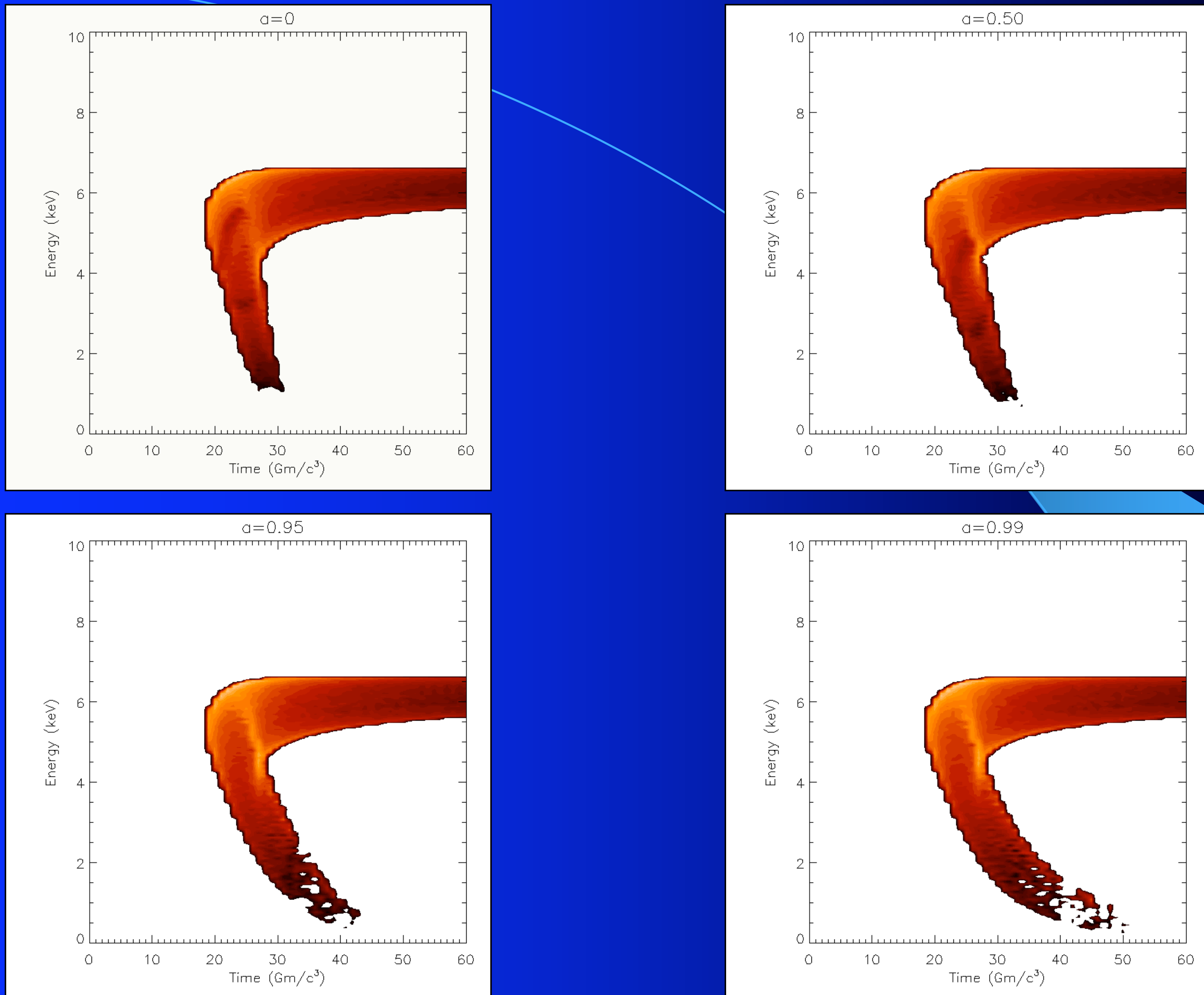


CSR et al. (1999)
Young & CSR (2000)

- Sensitive probe of strong gravity
  - Get inward and outward propagating X-ray echoes
  - inward propagating echo is purely a relativistic effect
  - Inward propagating echo gives red-bump on the iron line profile
  - Precise properties of red-bump are probe the Kerr metric (and allow measurement of BH spin)
- Side note… we already know that situation is not simple;
  - Current data suggest complex ionization changes associated with variability
  - Need hard X-ray capability of Con-X to deconvolve effects of disk ionization in a realistic spectrum.







Reynolds et al. (1999)

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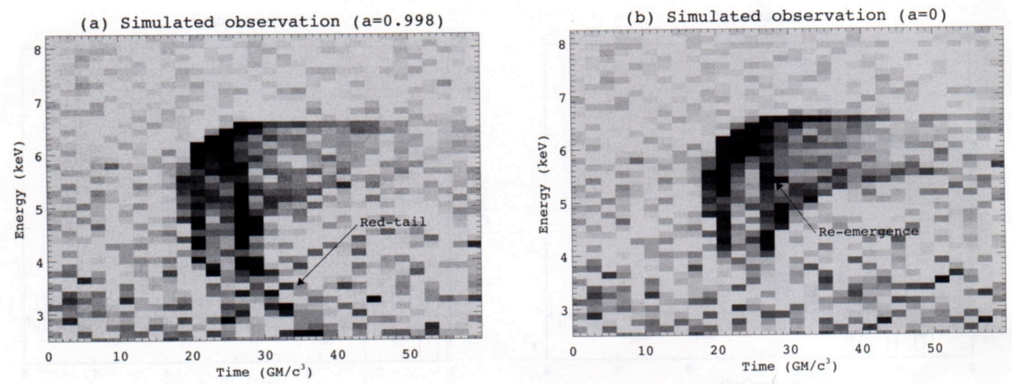

FIG. 4.—Simulated transfer function for (*a*) an extremal Kerr hole and (*b*) a Schwarzschild hole. In both cases, the flare has been placed on the symmetry axis at a height of $10GM/c^2$ above the disk plane, and an observer inclination of 30° has been assumed. The data have been rebinned to produce these figures with improved signal-to-noise ratio.

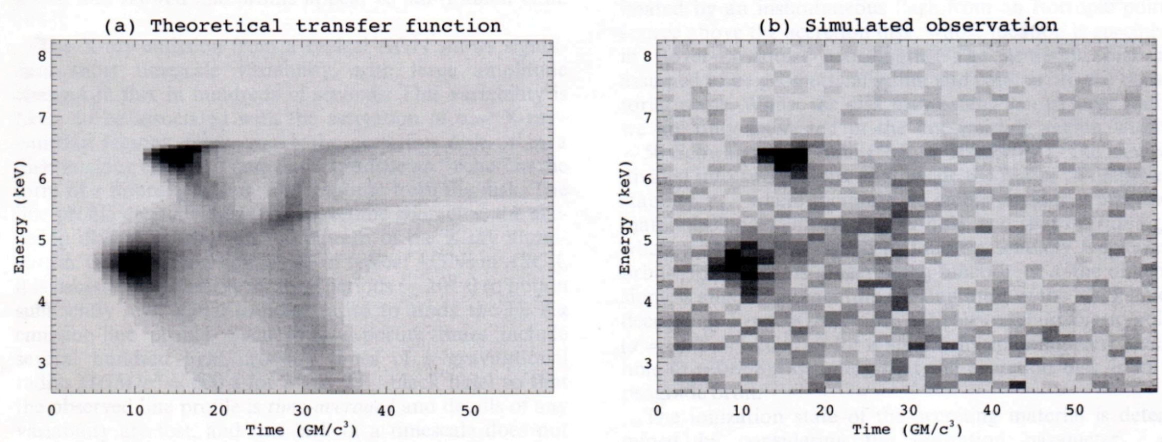

FIG. 7.—Panel *a* shows the theoretical line response to the two overlapping flares described in the text. Panel *b* shows the simulated line response as seen by *Constellation-X*. The individual transfer functions of the two flares can be discerned. The data have been rebinned to produce these figures with improved signal-to-noise ratio.

Constellation-X simulations

Conclusions

- **X-ray observations are already probing region in immediate vicinity of accreting stellar & supermassive black holes**

- X-ray astronomy is on the verge of realizing its ultimate promise (BHFP, Con-X, and BHI/MAXIM)
  - Probe of **BH growth** back to cosmic "dark ages"
  - Constraints on **strong field gravity**
  - Detailed understanding of **BH accretion**
  - Accessed through high-throughput spectroscopy (Con-X), and direct imaging (BHI)